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Search for solar cosmic ray records of early Sun in primitive meteorite phases

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Chondrules are some of the earliest formed silicate spherules in the solar system. According to their most accepted formation process, chondrules are nebular products and were floating in the interplanetary space for some time before becoming part of their parent body and are thus likely to have been exposed to the galactic cosmic rays as well as from early Sun. Our preliminary results of cosmic ray produced ^{21}Ne from carbonaceous chondrites show clear excesses in chondrules as compared to the bulk chondrite. This excess ^{21}Ne can not be due to compositional differences, but is consistent with a pre-compaction irradiation for < 1 Ma to galactic cosmic rays, and there does not seem to be any unambiguous record of exposure to early Sun.

1. Introduction

It has been shown recently [1] that T Tauri phases, wherein the particle fluxes in the young stellar objects with 0.8-1.4 solar masses are up to 10^5 times higher than for the recent solar SEP events. Such enhanced early solar activity could be partly or wholly responsible for the presence of now extinct short lived radioactive isotopes in the early solar system [2]. Also, several stable cosmogenic isotopes, notably the noble gas isotopes ^{3}He, ^{21}Ne and ^{38}Ar produced due to exposure to early solar activity are likely to be accumulated in the early solar system objects. Excess ^{21}Ne found in solar flare track rich grains from gas rich meteorites and carbonaceous chondrites could not be unambiguously attributed either to enhanced SEP activity of early Sun or extended exposure to GCR in parent body regoliths [3]. Calcium aluminum rich inclusions (CAIs) and chondrules are some of the earliest formed solid objects in the solar system and are believed to be nebular products [4] and as such should have been exposed to early solar activity and preserved such records as excess cosmogenic stable noble gas isotopes (^{3}He, ^{21}Ne and ^{38}Ar) as compared to their respective parent meteorites. Earlier attempts to search for such precompaction irradiation records have been concentrated on ensembles of chondrules separated from primitive chondrites [5]. In the present study, we have attempted to look for precompaction irradiation records, possibly due to exposure to enhanced solar activity in individual chondrules of carbonaceous (C) and unequilibrated ordinary chondrites (UOC), by laser probe noble gas mass spectrometry.

Chondrules: Chondrules are molten silicate spherules of ≤ 1 mm size and occur ≥ 50% by volume in chondritic meteorites. Petrological and mineralogical details of chondrules are consistent with their formation by flash heating and fast cooling in a nebular environment. The X-wind model [6] being a favorable contender, predicts the formation of chondrules very close (~ 0.06 AU) to the early Sun and hurled to the formation region of chondrites (2-3 AU) by the X-wind, to be later incorporated into their respective parent chondrites. Chondrules are thus expected to record the signatures of exposure to early solar activity, in addition to galactic cosmic rays (GCR), in the form of excess cosmogenic ^{3}He, ^{21}Ne and ^{38}Ar, during their precompaction nebular residence.

2. Experimental Procedures

Chondrules are separated from the bulk meteorite, either by gentle crushing to dislodge chondrules or by repeated freeze thaw process to disaggregate the meteorite, liberating the chondrules. Chondrules are hand picked under optical microscope; any adhering matrix material is gently scrapped off using dental tools and by cleaning in alcohol and acetone mixture, under ultrasonication. Each chondrule is photographically documented for its surface features, like presence of micro-craters, rims etc. and is accurately weighed by a microbalance. Those chondrules whose mass is ≥ 1 mg are split by gentle breaking, and a piece kept away for chemical, mineralogical and petrological characterization by SEM and EPMA. Chondrules with mass of ≤ 1 mg are fully utilized for noble gas measurements. Chondrules from carbonaceous chondrites Murray (CM2) and Allende (CV3) are studied for noble gases. While Murray chondrules are mostly <100 µg (except one exceptionally large chondrule, Murray 1, which is ~1 mg), those from Allende range from 0.39 to ~ 5 mg. Fig. 1 shows the pictures of the splits of large chondrules, taken from Allende and Murray carbonaceous chondrites, for physical, chemical and petrological characterisation.

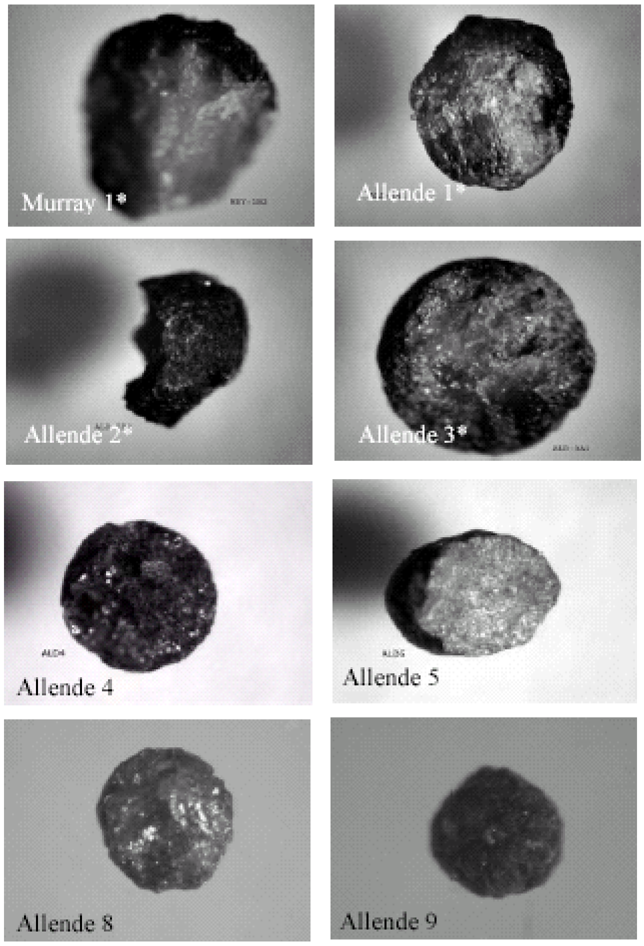

Fig.1. Images of the Murray (CM2) and Allende (CV3) chondrule splits saved for physico-chemical characterization. Sizes are not to scale.

Either splits (for large chondrules) or whole chondrules (for smaller ones) are loaded into tiny holes made in a Cu plan chat and pumped overnight under heat lamps (~150°C) to get rid off adsorbed atmospheric gases. The gas is extracted from the chondrules by heating with NdYAG laser working in CW mode at 1064 nm, in three steps by a defocused beam. Step 1 is for releasing adsorbed gases; step 2 is the melting step, while step 3 is a re-heat to ensure complete gas extraction. Complete details of extraction, purification and measurement are given in [7]. The data reported here has been corrected for blanks, interferences and instrumental mass discrimination as detailed [7]. Cosmogenic ^{21}Ne has been derived after correcting for trapped composition, using standard procedure [8], and the data is given in Table 1.

3. Results and discussion

Among the chondrules analysed, ^{21}Ne contents vary by a factor of 3.6 for Murray while in Allende the variation is only by a factor of 1.4. As the amount of cosmogenic ^{21}Ne depends both on chemical composition (mainly on Mg content) as well as on cosmic ray fluence, it is important to assess the role of each of these factors. The average Mg contents of chondrules from CV3 (Allende) and CM2 (Murray) chondrules are 21.1% and 26.0% respectively [9], while pure olivine, the most Mg rich mineral, in these classes of C-chondrites has upto 33% Mg [9]. Hence, a variation (above average) of only upto 60% for CV3 and 27% for CM2 can be expected in ^{21}Ne, due to variation in Mg contents. Since chondrules analysed from each meteorite are separated from a single piece of < 1 g, shielding differences are not a factor, in contributing towards ^{21}Ne differences. The variation observed among Allende chondrules might be explained due to chemical composition variations, but not for Murray chondrules. One need to invoke cosmic ray fluence changes as the main cause for the excess ^{21}Ne in at least chondrule Murray 1. We are presently in the process of determining the chemical composition of the chondrules by EPMA. We can nevertheless make an estimate of the cosmic ray fluence needed for the enhanced ^{21}Ne in Murray 1, under some valid assumptions.

The total cosmogenic ^{21}Ne in a chondrule is from two contributions; one produced during precompaction irradiation (by both SCR and GCR) and the other during the interplanetary sojourn as a meteoroid. We take average ^{21}Ne (in 10^{-8} cm^{3}STPg^{-1}) of Allende chondrules 3,5,8 and 9, as the average ^{21}Ne content (0.640) of Allende chondrules. One can see that the ^{21}Ne contents of Allende chondrules 2 and 4 are within (±20%) experimental uncertainities. Though the ^{21}Ne content for Allende 1 is higher (beyond ±20% over average), it can be easily accounted for by the possible Mg content variation of up to 60% for CV3 chondrules. Similarly, for Murray, taking the average ^{21}Ne of chondrules 5 and 8 (0.268) as the average ^{21}Ne in Murray chondrules due to irradiation as a meteoroid, we can attribute the ^{21}Ne of 0.529 in Murray 7 possibly due to the maximum expected variation in Mg content of ~50% and the measurement uncertainty of ±20%. But in case of Murray 1 the excess ^{21}Ne cannot be explained by considering the variation in chemical composition. Hence, to explain this observed excess ^{21}Ne the precompaction irradiation is required for Murray 1.

Assuming that Murray 1 is pure olivine, having maximum Mg content of 33% and other elemental composition given by [9], we calculate ^{21}Ne production rate for an average shielding to be 0.628x10^{-8} cm^{3}STPg^{-1}Ma^{-1} due to GCR. This requires a preirradiation of ~0.88 Ma, to generate the excess ^{21}Ne of 0.553 needed, assuming the GCR flux to be similar to that of contemporary era at a distance of 2-3 AU from the Sun. Even if we assume the average chondrule composition, instead of pure olivine [9], the production rate will decrease to 0.562x10^{-8} cm^{3}STPg^{-1}Ma^{-1} and the precompaction irradiation due to GCR will increase to 1.1 Ma. This free space irradiation time of 0.88 to 1.1 Ma is quite consistent with the formation time duration of chondrules based on extinct radioactive nuclides [10] and there does not seem to be any definite indication of excess cosmogenic ^{21}Ne (in the data available so far) above that produced by GCR that is attributable to solar cosmic rays.

Table 1. Cosmogenic ^{21}Ne in the chondrules

CHONDRULE [*SPLIT]	MASS [μg]	$^{21}Ne_C$ [10^{-8} cm^3STPg^{-1}]
Murray 1*	839	0.893
Murray 5	82	0.249
Murray 7	62	0.529
Murray 8	62	0.288
Allende 1*	3038	0.819
Allende 2*	2911	0.572
Allende 3*	1216	0.620
Allende 4	422	0.775
Allende 5	699	0.676
Allende 8	711	0.638
Allende 9	384	0.627

References

[1]. E.D. Feigelson et al., Astro. Phys. Journal. 572, 335 (2002).
[2]. J.N.Goswami et al., Astro. Phys. Journal. 547, 1151 (2001)
I Leya et al., Astro. Phys. Journal. 594, 605 (2003).
[3]. C.M.Hohenberg et al., Geochim. Cosmochim. Acta 54, 2133 (1990).
Wieler R. et al. Meteoritics 35, 251 (2000).
[4]. F.H Shu et al., Astro. Phys. Journal. (2001) 548, 1029 (2001).
[5]. E. Polnau et al., Geochim. Cosmochim. Acta 63, 925 (1999).
E. Polnau et al., Geochim. Cosmochim. Acta 65, 1849 (2001)
[6]. F.H. Shu et al., Science 271, 1545 (1996).
[7]. R.R. Mahajan et al., Proc. Ind. Acad. Sci. (EPS) 112, 113(2003).
[8]. O Eugster Geochim. Cosmochim. Acta 52, 1649(1988).
[9]. A.E.Rubin Meteoritics 21, 283(1986).
[10]. S. Mostefaoui et al., Meteorite Planet. Sci. 37, 421 (2002).